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Glassy carbon particles as component to modification of tribological properties

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The paper presents the results of research concerned with the influence of a glassy carbon addition on the tribological properties of metallic and polymeric matrix composites.
The research was conducted for two material groups: materials applied for friction lining in the automotive industry (polymeric matrix composites) and frictional materials with a metallic matrix. An addition of glassy carbon to friction composites with a polymeric matrix influences first of all the friction coefficient stability at an elevated temperature. An introduction of glassy carbon particles in a metallic matrix also makes the friction coefficient and wear decrease. The obtained composite can be used to produce sliding components cooperating at elevated temperatures, under high mechanical loads.

1. INTRODUCTION

The properties of composite materials can be shaped by a proper selection of reinforcing components, their form and volume fraction. Application of fibres and whiskers as a particles' reinforcing component contributes not only to a change of the mechanical properties but also such physical properties as: thermal conductivity, wear resistance, etc [1].
It is difficult, however, to obtain a material which would be characterized by e.g. high abrasion resistance and simultaneously ensure a low friction coefficient. As a rule, an introduction of hard and resistant to abrasion particles causes a reduction of composite's wear but, at the same time, it contributes to greater wear of the material co-operating with the composite in the friction centre. A reduction of the friction partner wear can be achieved by an application of two extremely different, in terms of their properties, types of reinforcing components, i.e. ones having typically abrasive properties and ones characterized by sliding properties, e.g. composites containing SiC particles and graphite [2,3]. Such composite materials, however, are difficult to produce from the point of view of the technology of their obtaining. It is possible to produce them when applying carbon of an amorphous structure (called glassy carbon) as the reinforcing component. This material, being an allotropic form of carbon, is characterized by high hardness and wear resistance [4, 5]. The choice of glassy carbon particles for the reinforcement is also dictated by their other advantageous properties, among which there are high strength at an elevated temperature, thermal and chemical stability, good thermal conductivity and resistance to thermal shocks. Tensile strength R_m and bending strength R_g at an ambient temperature and at 1000^oC do not change. Tensile and bending strengths of glassy carbon do not reduce at a temperature lower than $1200\text{-}3000^oC$.

Glassy carbon or composites with a glassy carbon matrix, reinforced with carbon fibre (C/C composites) are more and more frequently applied for friction and structural elements of brakes, since they have features not to be encountered in other groups of frictional materials. It is very difficult, however, to obtain this expensive material due to its production technology. Thus, the material discussed is applied in those friction centres which are particularly exposed to the action of great thrusts and high temperature (brakes in aircrafts). In order to enhance thermal resistance of those frictional materials that do not work under such extreme conditions, carbon materials are used, the simplest form of which is hardened resin carbonized at 500^{o}C, then ground and added to a composite as so-called frictional dust [6].
The paper presents an attempt at using glassy carbon particles to modify the tribological properties. Carbon in the form of particles can be added to materials with various matrix types. Glassy carbon has been developed in order to modify the tribological properties of two groups of frictional materials. An evaluation of the impact of glassy carbon has been carried out based on the characteristics of the friction coefficient and wear.

2. MATERIAL FOR RESEARCH

The research of the modifier's (glassy carbon) on the properties of composites was performed for two material groups:

- With a polymeric matrix; For the modification, some commercial materials were selected, used to produce brake lining in the car industry. They were traditional three-component materials consisting of a polymeric matrix (phenolic resin), reinforcing fibres (glass fibres, steel fibres) and fillers (metal and ceramic powders). A characteristic feature of these materials is a reduction of braking efficiency in the temperature range of 200-350 ^{o}C. The reason for the friction coefficient decrease at an elevated temperature is first of all the process of matrix destruction. The incorporation of glassy carbon particles into this group of materials was necessary in order to limit thermal destruction and stabilize the friction coefficient. The admixture of glassy carbon was introduced while mixing the frictional material components and the mixture so prepared was afterwards subjected to pressing. The incorporation of carbon did not require any change of the production technology conditions. The carbon particles had a diameter of ca. 100 μm and their w/w concentration varied from 2 to 10% [7].
- With metallic matrix. The composite matrix was an eutectic AK12 aluminium-silicon alloy modified with a 2% addition of manganese which reduces surface tension and improves wettability. The composite was obtained by casting method, by introducing particles (as a result of mechanical mixing) into a liquid metallic matrix. Having melted the AK12Mg2 aluminium-silicon alloy, the glassy carbon particles heated to a proper temperature were introduced into metallic bath in an argon atmosphere. To protect the particles against thermal destruction, protective layers were applied on them. After the required homogeneity of the suspension had been obtained, it was subjected to gravity casting into a metallic gravity die. The quantity of the particles introduced (of ca. 120μm granulation) accounted for 15% of the AK12Mg2 alloy volume. The material was produced and made in accordance with parameters established in the Silesian University of Technology [8], whereas reinforcing with glassy carbon particles is a solution not used so far in particle-reinforced metallic composites [9].

3. RESEARCH RESULTS

The intended use of the investigated materials required that the changes of their tribological properties be determined. The research focused on determining the friction and wear coefficients. In case of frictional composites with a polymeric matrix the research was conducted at an intertial test stand of a disk – shoe type. The change of the friction coefficient as a function of pressure and braking rate was determined. Also, measurement of the friction coefficient was made at an elevated temperature. A test at an elevated temperature allowed evaluation of the influence of carbon additive on the friction coefficient and its thermal stability. The research results are presented in Fig. 1.

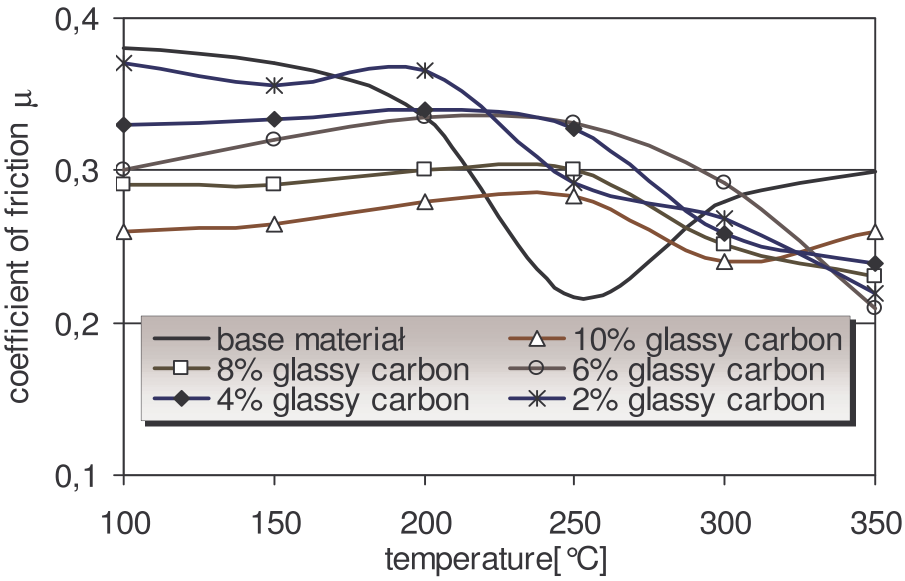


Figure1. Investigation results of friction coefficient in elevated temperature

Analysing the results obtained it can be found that a glassy carbon additive causes a reduction of the friction coefficient of a frictional material. The reduction depends on the quantity of the additive introduces. After adding 4-6%, the friction coefficient falls by ca. 10%. However, the presence of glassy carbon contributes to stabilization of the friction coefficient in the temperature range of 280-350°C. In case of a frictional material which does not contain glassy carbon, the friction coefficient rapidly falls at about 280°C, which leads to a loss of braking efficiency (temperature fading). The phenomenon of loss of the frictional material characteristics' stability results from thermal destruction of the matrix of the frictional composite – phenolic resin. An introduction of even small amounts of glassy carbon distinctly reduces fading, with a simultaneous increase of the temperature at which it takes place. With large amounts of glassy carbon (ca. 8-10%) the friction coefficient reduction in a critical temperature range is insignificant. Taking account of the glassy carbon's thermal characteristics (first of all, its thermal capacity of 150-200 W/mK as well as good thermal conductivity) one may assume that it accumulates the thermal energy generated during friction. This limits the processes connected with thermal distribution of the matrix material. Furthermore, an incorporation of glassy carbon contributes to a reduction of the frictional material wear. For a frictional material which does not containing carbon, the mass decrement amounts to 9,4 g, and for a materials containing 10% of carbon, ca. 3,7 g. Glassy carbon, although characterized by microhardness of ca. 3600 μHV, does not contribute to wear of the brake disk material [10]. The appearance of the disk surface cooperating with the frictional material testifies to this. After cooperation with a frictional material not containing glassy carbon, traces of microcutting and ridging are clearly visible on a cast iron disk (Fig. 2). However, a disk which cooperates with a material containing 8% of glassy carbon does not show such intensive processes of microcutting.

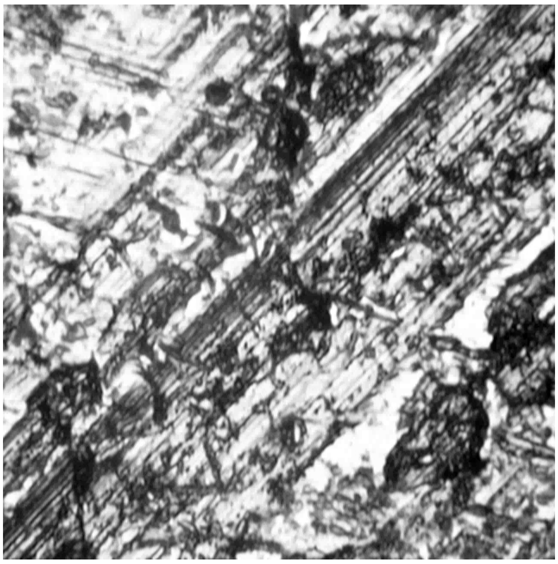
a)

b)


Figure 2. Appearance of a cast iron disk surface after cooperation with frictional material (a) not containing glassy carbon (b) with frictional material containing 8% of glassy carbon, (mag. 200x).

The second group of the materials investigated was a composite with an aluminium-silicon alloy matrix, AK12Mg2, which contained 15 wt.-% of glassy carbon. An evaluation of the tribological properties of this composite was performed by means of T01 device in a composite disk – cast iron pivot system. The research was conducted at a sliding speed from 0,1 to 1,0 m/s and loads of 20, 30 ,40 and 50 N (Fig3.).

The results of this research have shown that the composite's friction coefficient is about 0,12 and it does not change depending on the speed or load. For a comparison, composites with a DURALCAN aluminium matrix which contain ceramic SiC or Al_2O_3 particles are characterized by a friction coefficient amounting to ca. 0,45 - 0,5 [11]. Such a high value has been decisive when determining the use of these composites; they are used for, inter alia, brake disks which more and more frequently find application in the motor vehicle industry. Glassy carbon particles incorporated in an aluminium alloy enable using the composite for sliding components to replace aluminium matrix composites reinforced with graphite or mice particles.

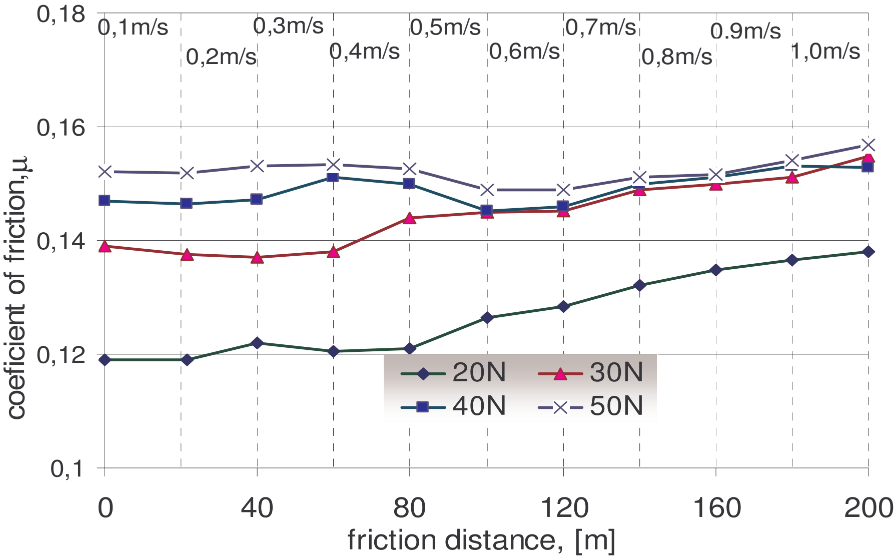


Figure3. Dependence of friction coefficient as a function of friction distance for cast iron sliding against a composite AK12Mg2- glassy carbon

Great hardness of glassy carbon particles (comparable to ceramic SiC or Al_2O_3 particles) does not cause major damage to the cast iron pivot being the friction partner to the composite material. The decrement in the cast iron pivot weight after investigation was ca. 2.4 mg. This results from the fact that it is mostly the glassy carbon particles characterized by a low friction coefficient that participate in the friction process. The appearance of the composite friction surface presented in Fig. 4 testifies to this. On a glassy carbon particle, regions of wear in the form of scratches are visible, whereas in the composite matrix, no traces of cooperation are visible. Only on the matrix surface, some wear products appear.

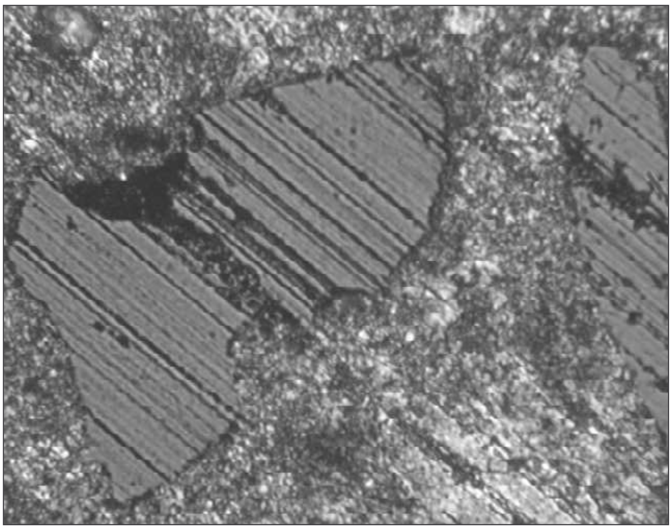


Figure 4. View of AK12Mg2- glassy carbon composite after sliding cooperation against cast iron with clearly visible scratches along the direction of the sliding partner move (mag. 160x)

4. SUMMARY

Glassy carbon can be used as a component to modify the tribological properties of frictional materials used, first of all, in the automotive industry. Its physicomechanical properties contribute to a reduction of the friction coefficient, but they have a very favourable influence on the friction coefficient stability at an elevated temperature. Thus, glassy carbon can be used to stabilize the tribological characteristics of clutch or brake friction lining. An addition of glassy carbon results in a reduction of the frictional material wear and simultaneously does not cause wear of the material cooperating with it in the friction centre.

After proper preparation, glassy carbon particles can be used as reinforcement in composite materials with a metallic matrix. A low friction coefficient of composites containing glassy carbon can be used to obtain sliding materials intended to work at elevated temperatures.

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